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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

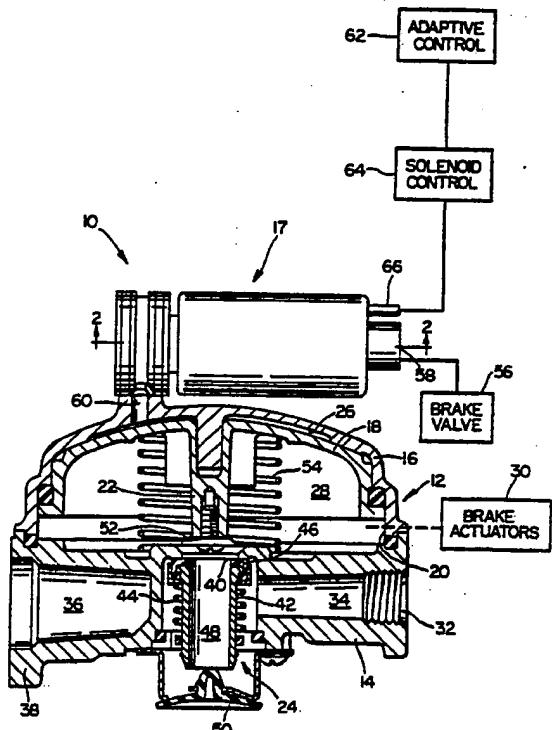
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(54) Title: METHOD AND APPARATUS FOR CONTROLLING PRESSURE LEVEL IN A COMPRESSED AIR ADAPTIVE BRAKING SYSTEM

(57) Abstract

Method and apparatus for controlling the pressure level in a compressed air adaptive braking system in which a single solenoid valve (17) is used to provide fast build and fast decay functions. The solenoid valve (17) is pulsed to control the pressure level in the control section (26) of the modulator valve so that a "slow build" or "pressure hold" state may be achieved with a single solenoid valve (17). The duty cycle of the pulses is chosen to control the pressure ratio between the input pressure and the pressure level to be achieved in the pressure hold or slow build state. The pulse rate is chosen sufficiently fast that the hysteresis of the control piston (18) prevents the valve from responding to the pressure fluctuations in the control section (26) to provide a "steady state" pressure level in the power section of the valve.



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METHOD AND APPARATUS FOR CONTROLLING
PRESSURE LEVEL IN A COMPRESSED
AIR ADAPTIVE BRAKING SYSTEM

This invention relates to a method and apparatus for controlling brake actuation pressure as a part of an anti-lock or electro-pneumatic brake actuating system for a heavy duty vehicle.

05 Compressed air braking systems include relay valves in which a pressure signal generated by the vehicle operator controls valve elements which control communication of compressed air from a reservoir to the vehicle foundation brakes. Such heavy vehicles that are 10 equipped with an anti-lock braking or electro-pneumatic system may incorporate one or more solenoid valves in the control section of the relay valve to thereby control braking pressure. Accordingly, relay valves (which are 15 commonly called brake pressure modulators if equipped with solenoid valves) use a relatively small volume of air in the control section to control a much larger volume of air that is necessary to operate the vehicle's brakes. Some systems now in use include a single three-way solenoid to 20 control pressure in the control section of the relay valve or modulator. The adaptive braking modulator therefor had two states, commonly referred to as "build" and "exhaust". When the solenoid is energized, the control section of the relay valve is exhausted to atmosphere, thereby promptly reducing braking pressure to allow the 25 controlled wheel to reaccelerate out of an incipient locking condition. When the solenoid valve is deenergized, the control section of the relay valve is reconnected to the brake valve controlled by the vehicle operator and operated as a normal relay valve, so that 30 braking pressure is abruptly increased. More sophisticated systems are equipped with a "brake pressure hold" or "slow build" state, instead of being restricted to only the full exhaust or full build states. This hold or slow build state enables the braking pressure to remain 35 close to the brake pressure at which skidding occurs, but just below it, for a substantial portion of each control

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cycle. Accordingly, air consumption is reduced, and control of the vehicle brakes is made much smoother.

To provide the "hold" or "slow build" state, modern modulators are provided with two solenoid valves.

05 One controls the inlet line and is normally open while the other controls exhaust to atmosphere and is normally closed. The pressure hold or slow build state is provided by energizing the inlet solenoid only. Other modulators have a single solenoid, but provide the slow build state 10 by use of so-called "pneumatic logic", in which mechanical components react to a pressure exhaust cycle to switch the valve into a slow build or pressure hold state. Either of these approaches is very expensive, because of the additional solenoid required in the two solenoid valve 15 systems, and because the components which are necessary to provide pneumatic logic are expensive. In addition, the pneumatic logic approach is inflexible in that only a single slow build rate is provided.

The present invention takes advantage of valve 20 hysteresis to provide a pressure hold or slow build capability in an adaptive braking modulator using only a single solenoid valve. Valve hysteresis occurs because seal friction and inertia of the mechanical valve parts of the valve prevent the control piston of a relay valve from 25 moving in response to small pressure excursions in the control section of the valve. The present invention takes advantage of valve hysteresis by rapidly pulsing a solenoid to control the pressure level in the control section of the valve during such a brake pressure hold or 30 slow build state. While substantial excursions around a mean pressure level will occur in the control section during such pulsing, these pressure excursions will not be felt in the power section of the relay valve or adaptive braking modulator if the pulse rate is high enough because 35 of valve hysteresis. Although some air is wasted in pulsing the control section, the quantity is minimal because the function of the relay valve in compressed air braking systems is to use a relatively low volume of air

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to control a much larger volume of air. Because of valve hysteresis, the large volume of air will be substantially unaffected. Even if the pulse rate cannot be maintained high enough to prevent all loss of air from the power side, small excursions in the power side of the adaptive braking modulator or relay valve will use less air than would otherwise be the case if a full build and full exhaust rates were the only control available. These and other advantages of the present invention will become apparent from the following description, with reference to the accompanying drawings, in which:

Figure 1 is a schematic illustration, partially in cross-section, of an adaptive braking system including a modulator, which is made according to the teachings of 15 the present invention;

Figure 2 is a cross-sectional view taken substantially along lines 2-2 of Figure 1;

Figure 3 is a graphical representation of the operation of an anti-skid system made pursuant to the 20 teachings of the present invention; and

Figure 4 is a graphical representation showing the relationship between pulse rate and duty cycle that controls operation of the adaptive braking modulator used according to the present invention.

Referring now to Figures 1 and 2 of the drawings, 25 an adaptive braking or electro-pneumatic modulator or relay valve generally indicated by the numeral 10 includes a housing 12 comprising a base portion 14 and a cover portion 16. A solenoid valve generally indicated by the numeral 17 is incorporated in the cover portion 16. A relay piston 18 is slidably mounted in bore 20 defined within the housing 12 and carries a valve operating member 22 which reciprocates with the piston 18. Valve operating member 22 controls a combination inlet/exhaust valve 30 generally indicated by the numeral 24 which is carried in the base portion 14. Accordingly, the relay piston 18 divides the housing 12 into a control section 26 and a 35 power section 28. The power section 28 is communicated to

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brake actuators illustrated schematically at 30 through outlet ports (not shown) spaced circumferentially about the base portion 14. An inlet port 32, which is communicated to a pressure source such as the vehicle air compressor, is communicated with an inlet passage 34 which is common with a passage 36 which communicates air to a storage reservoir (not shown) which is secured to mounting flange 38. The inlet/exhaust valve 24 controls communication between inlet passage 34 (which is common with the aforementioned reservoir) and the power section 28, and between the power section 28 and atmosphere. Inlet/exhaust valve 24 includes a valve seating area 40 carried on valve stem 42. A spring 44 yieldably urges valve seating area 40 into a sealing engagement with a circumferentially extending valve seat 46. The valve stem 42 is an annular member defining a passage 48 to thereby communicate power section 28 with atmosphere through conventional flapper valve 50. Communication between the power section 28 is cut off by engagement of valve member 52 carried on valve operating member 22 with the valve seating area 40. The piston 18, and therefore the valve member 52, are yieldably urged away from the valve seating area 40 by conventional spring 54.

A conventional brake valve 56 is mounted in the vehicle operator's compartment and, when actuated by the vehicle operator, communicates a pressure signal in the normal manner through inlet port 58 on solenoid valve 17 as will be more completely described with respect to Figure 2. This pressure signal, when the braking system is not operating in the adaptive mode, is communicated to the control section 26 through passage 60. Accordingly, when a brake application is effected by operation of the brake valve 56 when the braking system is not operating in the adaptive mode, the pressure signal is communicated into control section 26 to thereby yieldably urge the piston downwardly, so that valve member 52 first closes off the passage 48 and thereafter opens the valve seating area 40 by urging it away from the valve seat 46, to

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thereby permit braking pressure from the aforementioned reservoir to communicate to the brake actuators 30 through the power section 28. When the pressure levels in the power section 28 and control section 26 equalize, the 05 valve members 24 and 52 move to the lapped position, where the valve member 52 continues to sealingly engage the valve seating area 40 while the latter remains engaged with the valve seat 46. Further increases in pressure in the control section 26 will cause the inlet/exhaust valve 10 24 to open to permit pressure to build in the brake actuators 30; if the pressure level in the control section 26 is reduced, the valve member 52 moves away from the lapped position, permitting pressure in the power section 28 which is communicated with brake actuators 30 to bleed 15 out to atmosphere.

The adaptive braking system which operates the valve 10 includes an adaptive control pressure request circuitry 62, which may be of any conventional type well known to those skilled in the art. This control responds 20 electronically to vehicle wheel speed sensed by conventional electro-mechanical wheel speed sensors (not shown) to send a brake pressure request to solenoid control 64 to control braking pressure during incipient skidding conditions. Conventionally, both the adaptive 25 control pressure request 62 and the solenoid control 64 are incorporated within an electronic control unit which may be integrated as a part of an electronic package including the solenoid valve 17, or connected separately to solenoid terminal 66.

30 Referring now to Figure 2, solenoid valve 17 includes a housing 68 which mounts an inlet fitting 70 defining the inlet opening 58. A solenoid coil 72 is wrapped around the housing 68 and is connected to the terminal 66. An armature 74 is slidably mounted within 35 the housing 68 such that an annular passage 76 is defined between the outer circumferential surface of the armature 74 and the inner circumferential surface of the housing 68. The passage 76 communicates air from the inlet 58 to

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the passage 60 around the armature 74. The armature 74 carries valve seating members 78, 80 on opposite ends thereof. Valve member 80 controls communication through an exhaust port 82 which communicates passage 60 with atmosphere when the valve member 80 is moved away from exhaust port 82. An exhaust flap 84 covers the exhaust port 82, but is sufficiently flexible that air pressure exhausting through exhaust port 82 can deflect the exhaust flap 84 when braking pressure is exhausted from control section 26. The valve member 78 engages valve seat 86 on the end of the fitting 70 adjacent the armature 74. Accordingly, when valve member 78 is engaged with the valve seat 86, communication from the brake valve 56 through the inlet 58 is blocked. A spring 88 yieldably urges the armature to the left, viewing Figure 2, thereby yieldably urging the valve member 80 into sealing engagement with the exhaust port 82. However, when the solenoid 72 is energized, the armature 74 is moved to the right, viewing Figure 2, as is well known to those skilled in the art, thereby moving the valve member 80 away from the valve seat 82 and moving the valve member 78 into sealing engagement with the valve seat 86.

Referring now to Figure 3, a graph with respect to time of the pressure cycles and a typical adaptive braking compressed air brake application is illustrated. In segment A-B, the system is not in the adaptive mode. In this condition, the solenoid valve 17 is deenergized, so that the brake pressure called for by the vehicle operator in actuating brake valve 56 is communicated through inlet opening 58, passages 76 and 60, and into the control section 26 of the modulator or relay valve 10. Pressure in the control section 26 operates the relay piston 18, thereby opening the inlet exhaust valve 24 to effect a brake application. Pressure builds in the brake actuators as shown in segment A-C. At some point (labeled B in Figure 3), the adaptive control senses an incipient skidding condition. At this time, adaptive control 62 signals the solenoid control 64 to effect a brake pressure

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reduction. Because of the reaction time involved, the brake application overshoots the "skid" pressure indicated by the dashed horizontal line in Figure 3 by the amount B-C. The "skid" pressure is that pressure in the brake actuator 30 at which the incipient skidding condition occurs. Accordingly, valve 17 is actuated, thereby venting the passage 60 to atmosphere through the exhaust port 82. An abrupt pressure reduction C-D then occurs, which takes the braking pressure well below the skid pressure. At point D, the adaptive control 62 senses that an incipient skidding condition no longer exists, and thereby signals the solenoid control valve 64 to rebuild braking pressure. The rebuild of braking pressure is illustrated in segment D-E of Figure 3.

15 Point E is still below the "skid" pressure. However, it is desirable to maintain braking pressure close to, but just below, the "skid" pressure. In this way, the braking pressure is maximized without causing a skid, so that stopping distance is as short as possible 20 while preventing skidding, and compressed air consumption is also minimized. If repeated pressure decay such as that illustrated in C-D were to occur, a significant volume of compressed air would be needlessly consumed. Accordingly, it is desirable to perform a brake pressure 25 hold or slow build cycle during the segment represented by line E-F in Figure 3. Segment E-F is illustrated as a slow build cycle, but, depending upon system requirements, could be effected as a brake pressure hold cycle. At point F, the system again senses an incipient skidding 30 condition and decays braking pressure by actuating solenoid valve 17 continuously, as illustrated in segment F-G.

According to the invention, a brake pressure hold or slow build state, as represented by line segment E-F in 35 Figure 3, is attained by pulsing the solenoid valve 17 at a duty cycle sufficient to maintain a desired pressure state, which may be either a pressure hold state or a slow build state, in the control section 26. Referring to

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Figure 4, the term "duty cycle" refers to the percentage of time that the solenoid valve 17 is actuated. For example, both curves A and B in Figure 4 represent a 50% duty cycle, because in both cases the valve is turned on 05 for 50% of the time. Similarly, if the valve were turned on 75% of the time, the duty cycle would be 75%, and if the valve was actuated only 25% of the time, the duty cycle would be 25%. The pressure level at the outlet of the solenoid, represented by the pressure level in passage 10 60 and control 26, as a fraction of the pressure level at inlet 58 of the solenoid is a function of the duty cycle at which the valve 17 is pulsed. For example, if the pressure level at point E in Figure 3 is to be 50% of the input pressure called for by the vehicle operator at inlet 15 58 by operation of valve 56, the solenoid control 64 would call for a 50% duty cycle when the adaptive control 62 signaled the beginning of the slow build state represented by line segment E-F in Figure 3. Depending upon a number of factors, a duty cycle of more or less than 50% may be 20 necessary to achieve a 50% pressure reduction. If a slow build state is desired, the solenoid control 64 would gradually decrease the duty cycle in a predetermined manner during the slow build state, so that the solenoid would be progressively energized for a reduced portion of 25 the total on/off time. Duty cycle controls such as that illustrated schematically at 64 in Figure 1 are old and well known to those skilled in the art, and will not be disclosed herein.

An important feature of the present invention is, 30 regardless of the duty cycle called for, the pulse rate is maintained at a sufficiently high rate that valve hysteresis, including the friction of the seals between the piston 18 and housing 12, inertia of the piston and the various valve components, etc. is such that the piston 35 18 does not move in response to the pressure fluctuations in the control section 26, or at most a very small amount. Referring to Figure 4, both curves A and B have the same 50% duty cycle as disclosed above. However, the

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pulse rate of curve A is twice that of curve B. In other words, the solenoid 17 may be pulsed at a pulse rate sufficiently great that hysteresis of the piston 18 and the other components of the valve 10 is not overcome, 05 while the duty cycle is adjusted as necessary to provide the required mean pressure level in the control section 26. Obviously, since the valve 17 is being pulsed, substantial fluctuations will occur about the mean pressure level in the control section 26. However, this 10 mean pressure level will be the pressure level called for by the duty cycle solenoid control 64. Accordingly, although compressed air will continually be exhausted and then rebuilt in the control section 26, the mean pressure level will be substantially that illustrated in, for 15 example, the slow build state illustrated by line segment E-F in Figure 3. Due to the aforementioned valve hysteresis, and depending upon the ratio of the volumes of the power section 28 and the control section 26, and also depending on the solenoid flow characteristics, the 20 pressure fluctuations in the power section 28 will be negligible, so that air consumption will be very small if not zero.

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Claims

1. Method of controlling the pressure level in a compressed air braking system having a compressed air source, brake actuators operated by compressed air from said source, and a control valve for controlling communication between said pressure source and said brake actuators, said control valve including a power section for controlling the pressure level communicated to said actuators, a control section for controlling the fluid pressure level in the power sections as a function of the pressure level in the control section, the pressure level in the control section being controlled by a single electrically actuated valve switchable between energized and deenergized states, comprising the steps of establishing an established pressure level in the power section when the electrically actuated valve is in the deenergized state, decreasing the pressure level in the power section at a predetermined rate to a minimum pressure level by switching the electrically actuated valve to the energized state to thereby communicate the control section to atmosphere, and establishing a controlled pressure level in said power section which is at or above the minimum pressure level but less than the established pressure level by switching said electrically actuated valve between said states at a predetermined pulse rate, said pulse rate being at a frequency which exceeds the rate at which the control valve is able to respond to assure that pressure fluctuations in the power section of the control valve will be of lesser magnitude than the pressure fluctuations in the control section of the control valve in response to switching of the electrically actuated valve between said states.

2. Method of controlling the pressure level in a compressed air braking system as claimed in claim 1, wherein the rate of change of the pressure level in said power section is established by controlling the duty cycle of said predetermined pulse rate.

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3. Method of controlling the pressure level in a compressed air braking system as claimed in claim 2, wherein said control section is communicated with operator actuated valve means actuatable to establish said 05 established pressure level in said control section, said duty cycle being controlled to establish a constant pressure level in said power section which is less than the pressure level established by the vehicle operator.

4. Method of controlling the pressure level in a 10 compressed air braking system as claimed in claim 2, wherein said control section is communicated with operator actuated valve means actuatable to establish said established pressure level in said control section, said duty cycle being controlled to establish a pressure level 15 in said power section which increases from the minimum pressure level at a controlled rate less than the rate of pressure increase that would occur if the electrically actuated valve was deenergized continually while maintaining said pulse rate at a frequency at which 20 pressure excursions around said controlled rate in said power section are less than the pressure excursions around said controlled rate in the control section.

5. Method of controlling the pressure level in a compressed air braking system as claimed in claim 1, 25 wherein said control valve includes valve components for controlling the pressure level in the power section and a valve components operating device responsive to the pressure level in the control section for operating the valve components for controlling the pressure level in the 30 power section, said valve components and operating device due to hysteresis being unable to respond directly to pressure fluctuations greater than a predetermined frequency, said predetermined pulse rate being greater than said predetermined frequency.

35 6. Compressed air braking system having a compressed air source, brake actuators operated by compressed air from said source, a control valve for controlling communication between said source and said

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brake actuators, valve components within said housing for controlling communication between said source and said brake actuators, and a valve components operating device responsive to a control pressure level in a control section of the control valve, said pressure level in the control section being controlled by electrically actuated valve means switchable between energized and deenergized states, said electrically actuated valve means being switched to said energized state to initiate a brake pressure decrease cycle to decrease the pressure level in said control section at a predetermined rate, and means switching the electrically actuated valve means between said energized and deenergized states at a pulse rate greater than the rate that the operating device can respond to the pressure fluctuations caused by said pulse rate so that the pressure variations in said brake actuators are lower in magnitude during switching at said pulse rate than the pressure variations in said control section.

7. Compressed air braking system as claimed in claim 6, wherein said switching means also controls the duty cycle of said predetermined pulse rate to establish a controlled pressure level in said brake actuators which is less than the pressure level generated by the operator by operating said operator actuated valve means.

8. Compressed air braking system as claimed in claim 7, wherein said control section is communicated with said operator actuated valve means to establish said established pressure level in said control section, said duty cycle being controlled to establish a pressure level in said brake actuators which increases from the minimum pressure level established at the conclusion of said brake pressure decrease cycle at a controlled rate less than the rate of pressure increase that would occur if the electrically actuated valve was deenergized continually while maintaining said pulse rate at a frequency at which pressure excursions around said controlled rate in said

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brake actuators are less than the pressure excursions around said controlled rate in the control section.

9. Compressed air braking system as claimed in claim 7, wherein said control section is communicated with 05 an operator actuated valve means to establish said established pressure level in said control section, said duty cycle being controlled to establish a pressure level in said brake actuators which is less than the pressure level established by the vehicle operator by operation of 10 said operator actuated valve means.

10. Compressed air braking system as claimed in claim 6, wherein said control valve includes a power section controlled by the pressure level in the control section by operation of the valve components, the volume 15 of said power section being substantially greater than the volume of the control section so that the pressure excursions in the power section will be less than the pressure excursions in the control section when the electrically actuated valve is switched between said 20 states at said pulse rate.

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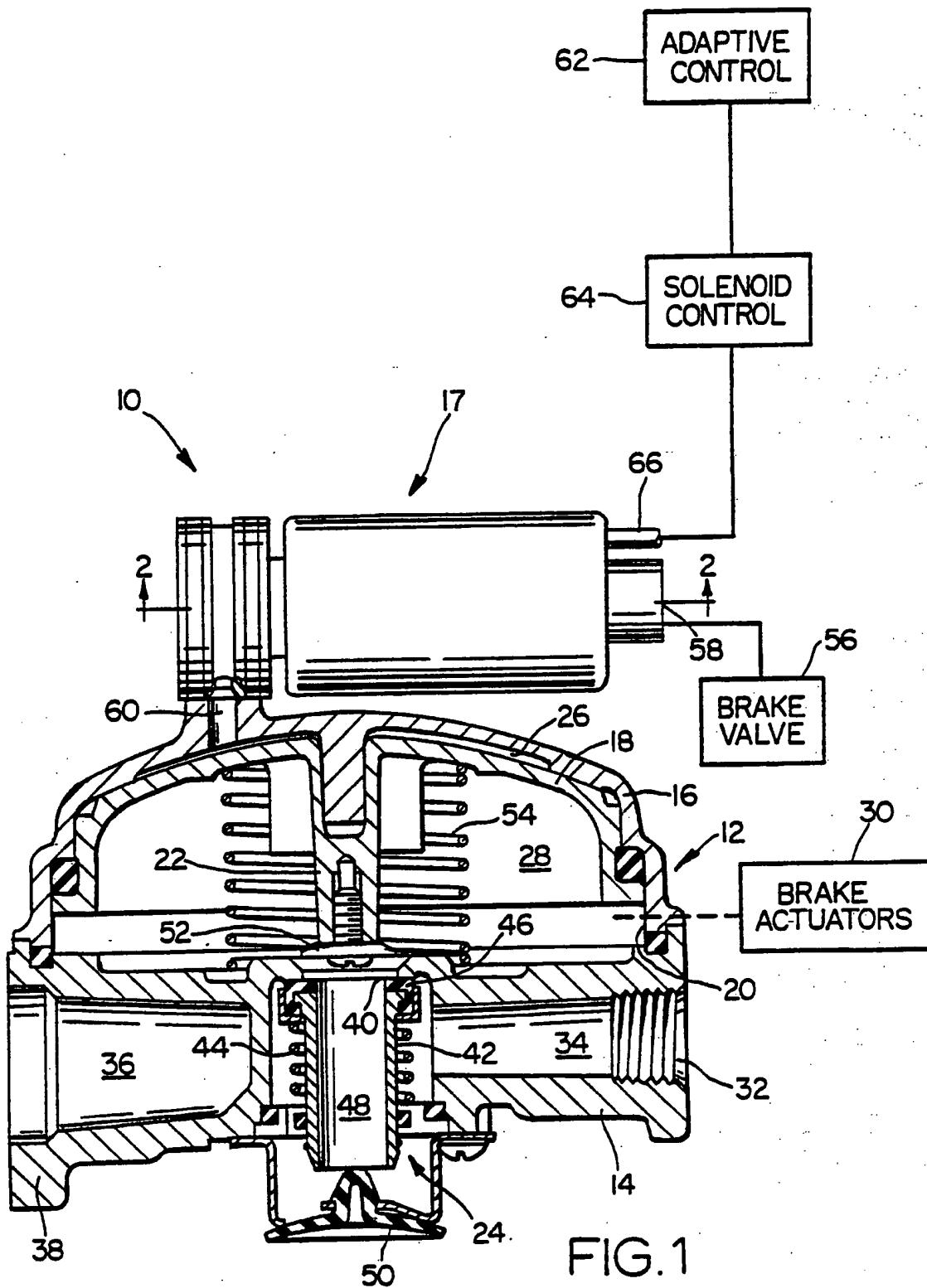


FIG.1

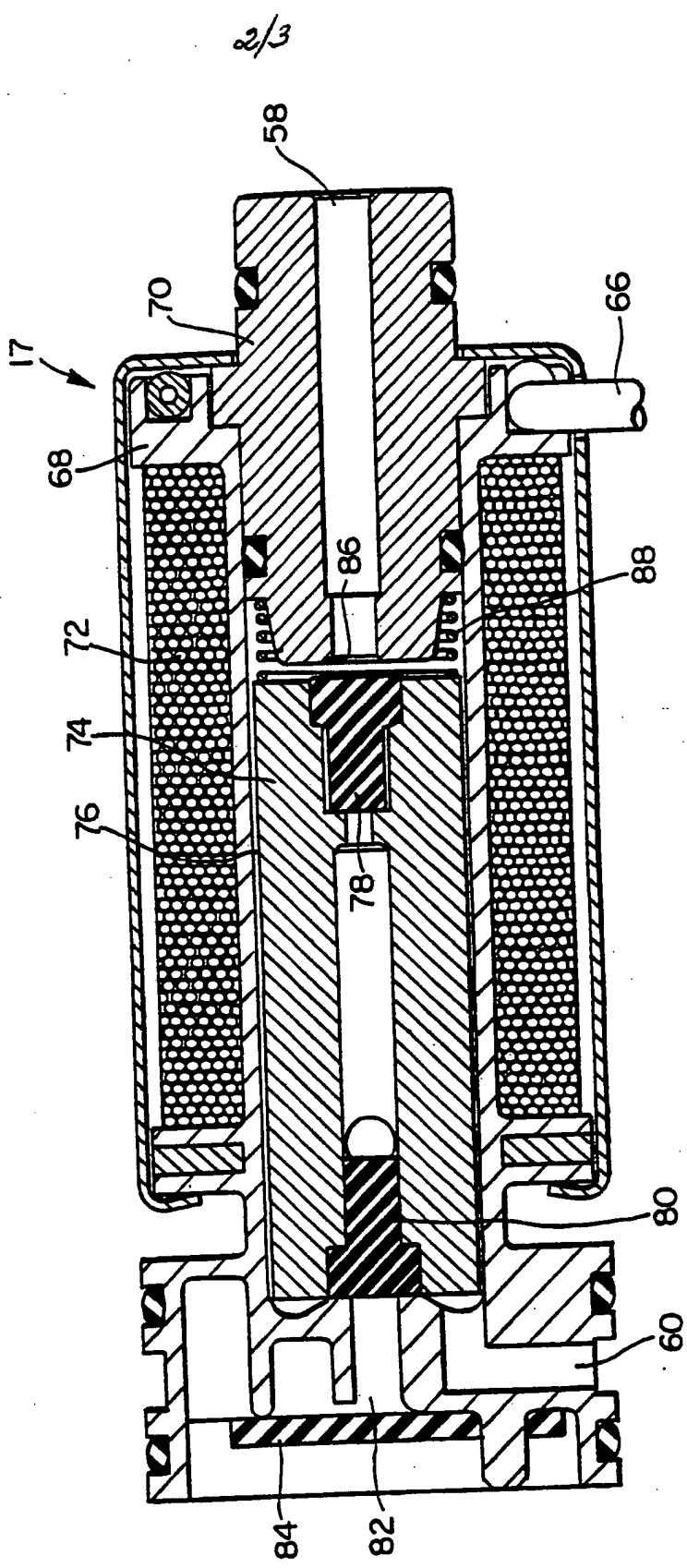


FIG. 2

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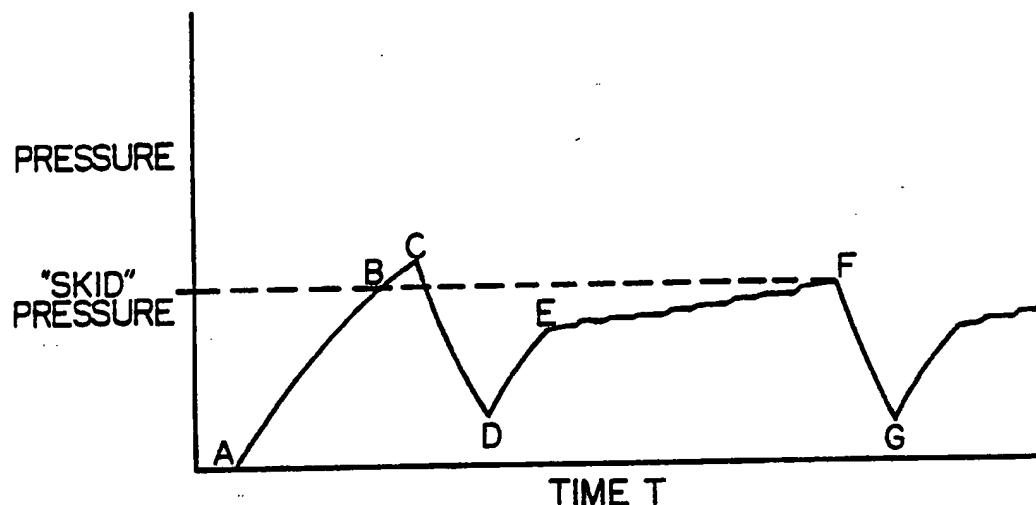


FIG. 3

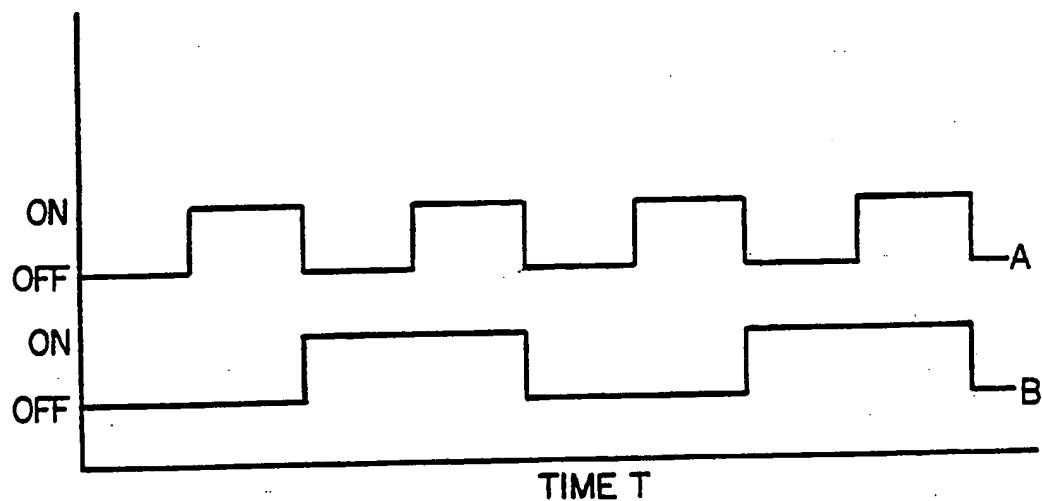


FIG. 4

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 91/04231

I. CLASSIFICATION OF SUBJECT MATTER (If several classification symbols apply, indicate all)⁶

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 B60T8/50; B60T8/36

II. FIELDS SEARCHED

Minimum Documentation Searched⁷

Classification System	Classification Symbols
Int.Cl. 5	B60T

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched⁸III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹

Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US,A,3 743 362 (NEISCH) 3 July 1973 see column 4, line 10 - column 5, line 67; figures 1-3,6	1,2,4-10
A	---	3
A	DE,A,2 500 483 (ROBERT BOSCH) 15 July 1976 see page 4, paragraph 2 - page 5, paragraph 1; figure 1	1,6
A	FR,A,2 160 465 (THE BENDIX CORP.) 29 June 1973 see page 4, line 31 - page 7, line 9; figures	1,6
A	SOVIET INVENTIONS ILLUSTRATED Section P/Q, week 8431, 12 September 1984 Derwent Publications Ltd., London GB. *class Q1, page 8, no. 84-1938846/31* & SU-A-1057349 (POLT) 30 November 1983	1,6

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¹¹ T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention¹² X document of particular relevance; the claimed invention cannot be considered novel, or cannot be considered to involve an inventive step¹³ Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

& document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search

3

31 JANUARY 1992

Date of Mailing of this International Search Report

24.02.92

International Searching Authority

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MEIJS P.

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	FR,A,2 532 258 (ANTI-SKID CONTROLS LTD.) 2 March 1984 see page 4, line 11 - page 6, line 25 see page 8, line 35 - page 9, line 24; claims 1,5; figures 1,4-6 ----	1,6

ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. US 9104231
SA 52975

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
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